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Abstract

We examine various options for calibration of NIF neutron detectors in the energy region E<14 MeV. These options include: downscatter of D-T fusion neutrons using plastic targets; nuclear reactions at a Tandem Van de Graaf accelerator; and "white" neutrons from a pulsed spallation source. As an example of the spallation option, we present some calibration data that was recently obtained with a single crystal CVD diamond detector at the Weapons Neutron Research facility (WNR) at LANL.

I. Introduction

In order to achieve fusion ignition and propagating burn at the National Ignition Facility (NIF), a fuel areal density of ~1 g/cm^2 must be achieved in the laser compressed DT capsules. It has been suggested [1] that the fuel areal density could be diagnosed by measurement of the primary-to-downscattered-primary fusion neutron ratio (i.e. the fraction of primary 14 MeV fusion neutrons which downscatter in the fuel). In order to obtain an accurate measurement, the sensitivity of the neutron detectors must be known as a function of energy for E<14 MeV. Although calibration at 2.5 and 14 MeV is straightforward (e.g. via implosion of DD and DT fuels respectively) the calibration at other energies is non-trivial, and is the subject of this paper. The organization of this paper is as follows: we start with a general discussion of neutron detector sensitivity; and then we suggest three separate options for calibration in the energy region E<14 MeV.

II. Neutron detector sensitivity

The specific quantity of interest for neutron detector calibration is the sensitivity (S) which is the collected charge per incident neutron. For a solid state device, the collected charge is defined to be the induced charge on the electrodes prior to amplification (if any). For a scintillator, the collected charge is defined to be the number of photoelectrons produced at the PMT photocathode.

The sensitivity can be directly measured in an Inertial Confinement Fusion (ICF) facility by integration of the current pulse shape as recorded by a high bandwidth scope. This set up typically involves connecting the detector (with or without amplification) to a bias-T which enables both application of bias and connection to the scope. In this situation, the sensitivity is calculated as follows:

$$S = \int V(t)/(50\Omega * n * e) \quad , \tag{1}$$

where V(t) is the pulse signal in volts recorded as a function of time (seconds), 50Ω is the termination of the scope, n is the number of incident neutrons, and e is the electron charge in Coulombs.

Alternatively, the sensitivity can be measured via single neutron counting at a D-T neutron generator, spallation source, or other neutron beam facility. The set up here typically involves a preamplifier, amplifier, and ADC. In this case, the sensitivity is calculated as:

$$S = \int C(ch)*a/n, \qquad (2)$$

Where C is the number of counts per ADC channel (ch), a is the number of electrons per ADC channel as determined via a calibrated pulser into the preamplifier, and n is the number of incident neutrons.

Although the calibration techniques described in this paper are applicable to arbitrary detector modality (e.g. solid state device, scintillator), we will focus on diamond detectors [2,3]. For diamond, calculations using the ENDL nuclear database suggest that the sensitivity curve as a function of energy should look like Figure 1. This curve assumes a charge collection distance of 50 microns as measured in [2]. The corresponding curve for a plastic scintillator should be smoother, but will also show some energy dependent perturbations due to the presence of carbon in the scintillator material.[4]

III. Calibration using downscattered OMEGA/RTNS neutrons

We can downscatter 14 MeV neutrons with plastic to create neutrons of arbitrary energy <14 MeV depending upon the angle of scatter. In Figure 2 we illustrate a geometry that could be used at either OMEGA or the RTNS neutron generator. The movable ring provides the option of variable neutron energies by varying the angle of scatter, while the annular shape maximizes the scattered neutron yield. Figure 3 shows the simulated neutron spectrum at the diamond detector for a 7 MeV ring location. In implementing this design at an actual neutron facility, an Inertial Confinement Fusion (ICF) machine like OMEGA will have the advantage of pulsed operation which allows the use of TOF techniques to reduce background. However, if the ring could be constructed out of plastic scintillator elements, a coincidence trigger between the scintillator and diamond detector could allow low noise operation at neutron generators like the RTNS. We plan to explore both approaches in the future.

IV. Calibration using a 9MV Tandem Van de Graaff accelerator

Reactions like $^{2}H(d,n)$, $^{1}H(T,n)$, and $^{1}H(^{11}B,n)$ can be used to produce monoenergetic neutrons in certain energy ranges which, if overlapped, can satisfy the energy range of interest.[5] The detector should be placed at 0 degrees to maximize yield. One convenient Tandem Van de Graaf accelerator is the CAMS facility located at LLNL. Discussions that have taken place with the CAMS staff indicate that this is a viable option, and may be pursued further in the future.

V. Calibration at the WNR

The Weapons Neutron Research facility (WNR) at LANL produces a neutron flux by spallation of tungsten with 800 MeV protons.[6] The proton beam is pulsed with a time structure that involves sub-ns wide micro-pulses separated by (typically) ~2μs. The spallation process in tungsten produces a broad neutron spectrum from ~0 to ~800 MeV. In March 2004, we took some data at the WNR with the single crystal CVD diamond detector. The detector was located in bldg 1265 (the ICEHOUSE) along the flight path known as 4FP30L. The distance from the "Target 4" neutron production site to the detector was 20m.

Figure 4 shows the electronic set-up used in this experiment. Both time-of-flight spectra (figure 5) and time-gated pulse height spectra (figure 6) were recorded. The data in figure 6 represents the first pulse height spectra ever obtained (to our knowledge) for diamond detectors in the $2.5<E<14$ MeV range. The high noise level in the NIM based fast amplifier that feeds the TAC (and thus sets the gate for the ADC) limits the energy threshold in these spectra to ~1 MeV. This high threshold prevents us from extracting sensitivity numbers because too much of the diamond detector response lies below 1 MeV (primarily the elastic scattering component). However, the (n,α) peak is clearly visible in the spectrum, and its behavior vs. energy seems reasonable (but not in exact agreement with the ENDL database).

In future experiments at the WNR, it is recommended that the NIM-based fast amplifier in Figure 4 be replaced with a custom built, low noise, fast amplifier (e.g. something from Picosecond Pulse Labs, Colorado). This could greatly lower the energy thresholds in Figure 6, and should allow accurate sensitivity measurements to be made. However, with lower thresholds, the micropulse spacing in the beam time structure should be lengthened considerably so as to avoid neutron pulse overlap (a spacing $\gg 2$ μs is recommended).

VI. Conclusions

Many options are available for calibration of NIF neutron detectors in the region below 14 MeV. We have outlined some of the possibilities here, and have made suggestions for future work.

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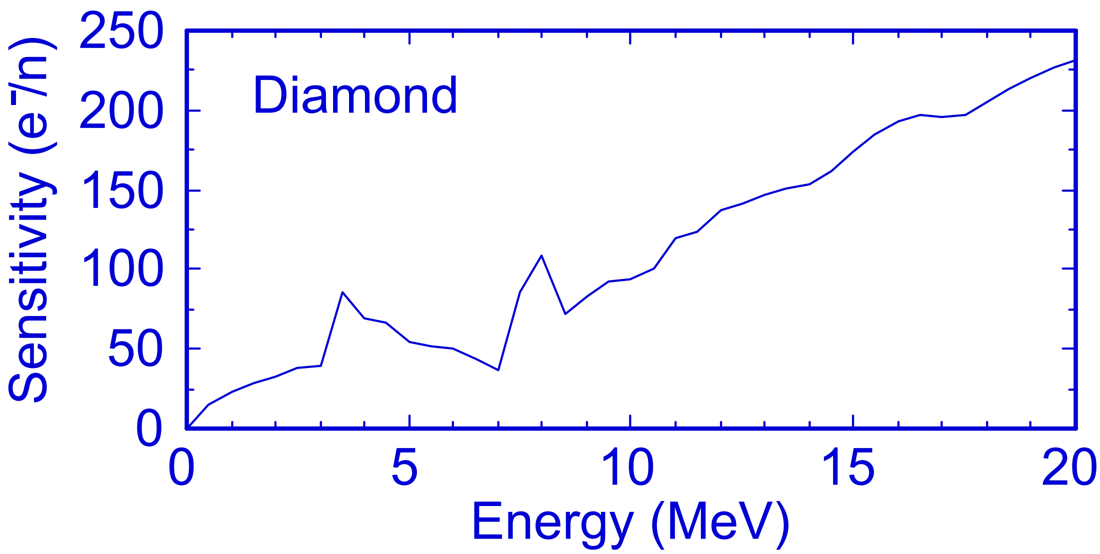

Fig.1: Sensitivity for a 1mm thick diamond wafer with a 50μ charge collection distance.

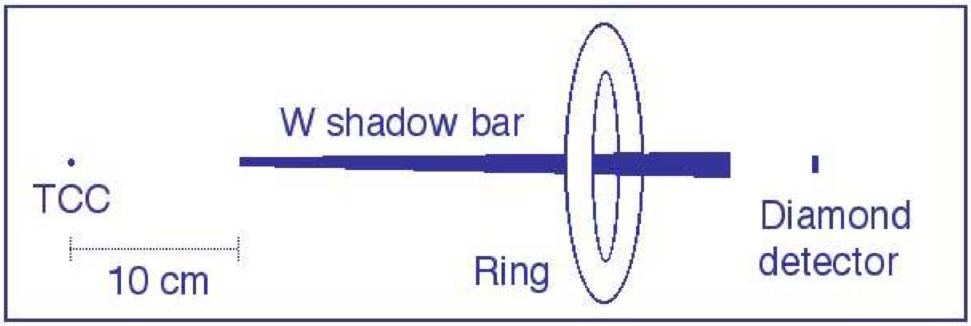

Fig.2: Proposed geometry for OMEGA/RTNS experiment to obtain 7 MeV neutrons at the diamond detector. The plastic ring is at 32 cm from TCC (i.e. the neutron generation point) and the diamond detector is at 45 cm from TCC. The tungsten shadow bar blocks the direct 14 MeV neutrons. If the plastic ring is moved further or closer to TCC along the same axis, other energies can be obtained

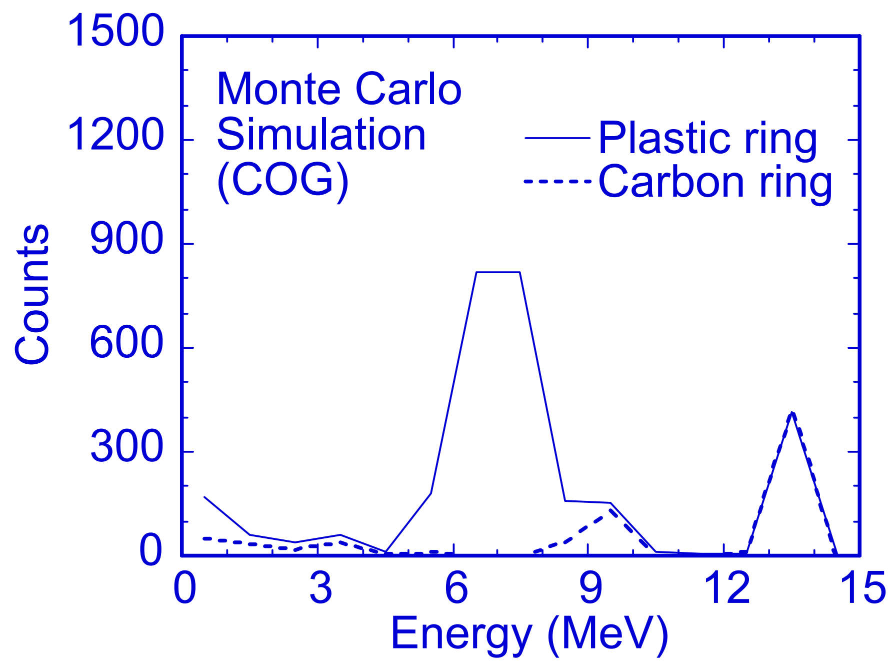

Fig.3: Simulated neutron spectrum at the diamond detector location for the geometry in Fig.2 (solid line). The feature at 13 MeV is due to scattering in the carbon of the CH_2 ring. By taking data using a pure carbon ring, this background component can be accurately determined (dashed line).

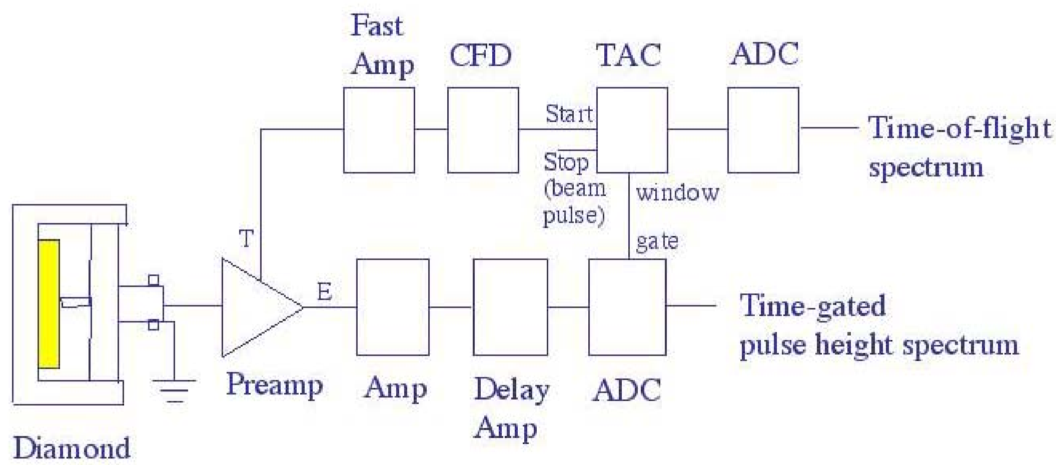

Fig.4: Detector and electronics set up for theWNR experiment. The diamond detector is located 20 meters from the spallation target. The preamplifier is an ORTEC 142A standalone module. The other electronics modules are NIM-based.

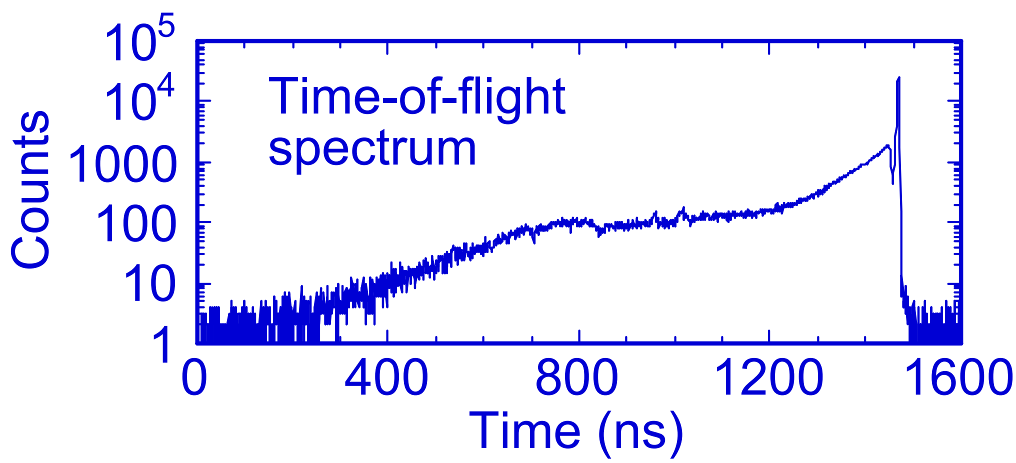

Fig.5: Time-of-flight spectrum for the diamond detector at the WNR. Flight time goes from right to left on this plot. The timing resolution, as indicated by the fwhm of the γ-flash (large peak on right), is ~4ns. This suggests an energy resolution of 300 keV at 14 MeV. The lower threshold in this spectrum is equivalent to ~1 MeV, and is likely due to noise in the NIM-based fast amplifier.

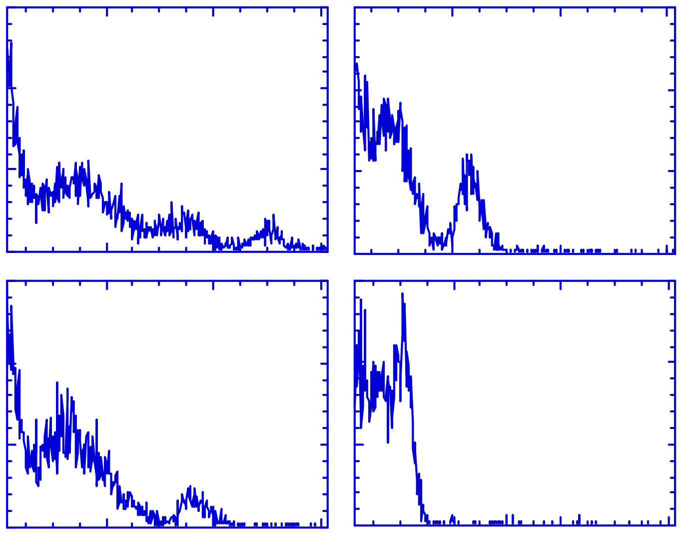

Fig.6: Time gated pulse height spectra for the diamond detector at the WNR. The gates are set by adjusting the time window on the TAC output which gates the ADC. The limits of this window was chosen so as to create 500 keV wide energy bins at 14,12,10, and 8 MeV respectively. The energy threshold in these spectra is ~1 MeV. Since much of the diamond response is < 1 MeV, lower energy thresholds are needed to obtain sensitivity measurements. This will be pursued in future experiments.